CF6 Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities

Conveners:
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Joint analyses of different maps breaks degeneracies, allowing us to reach projected sensitivities to DE, inflation

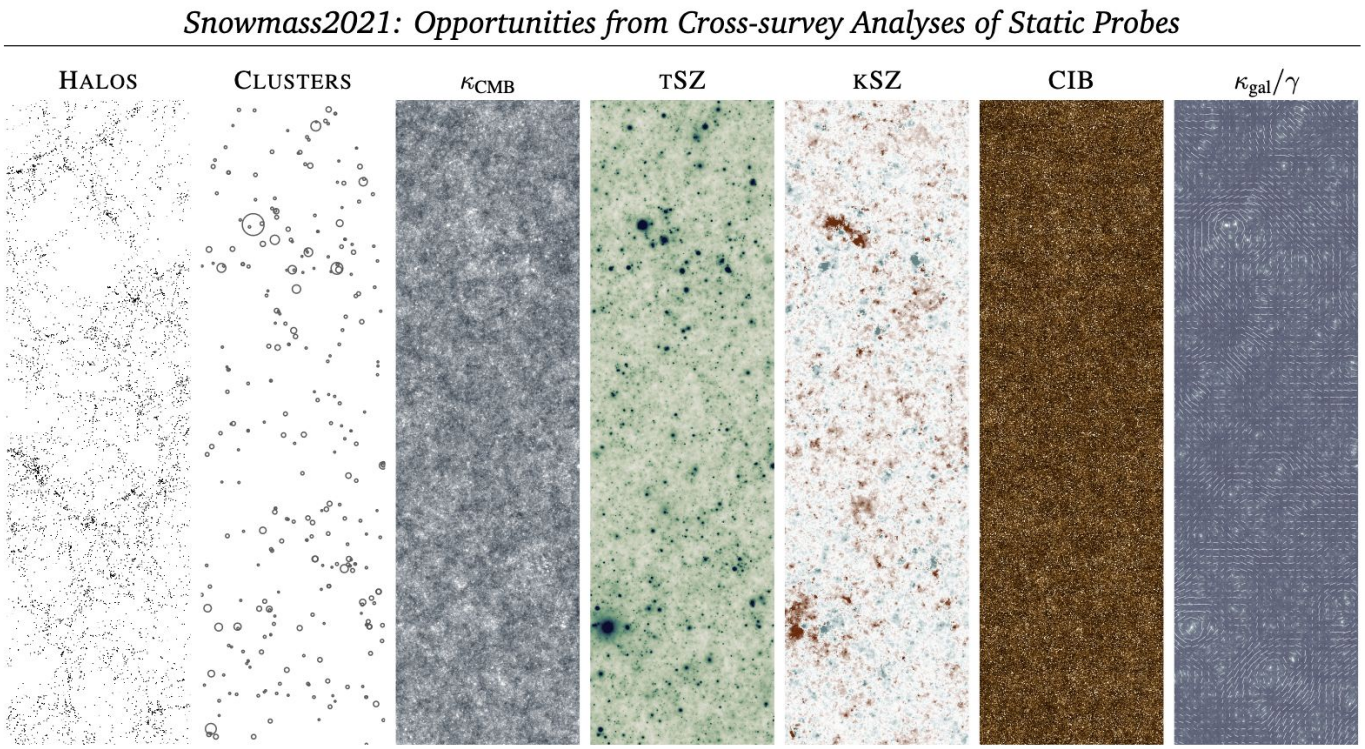
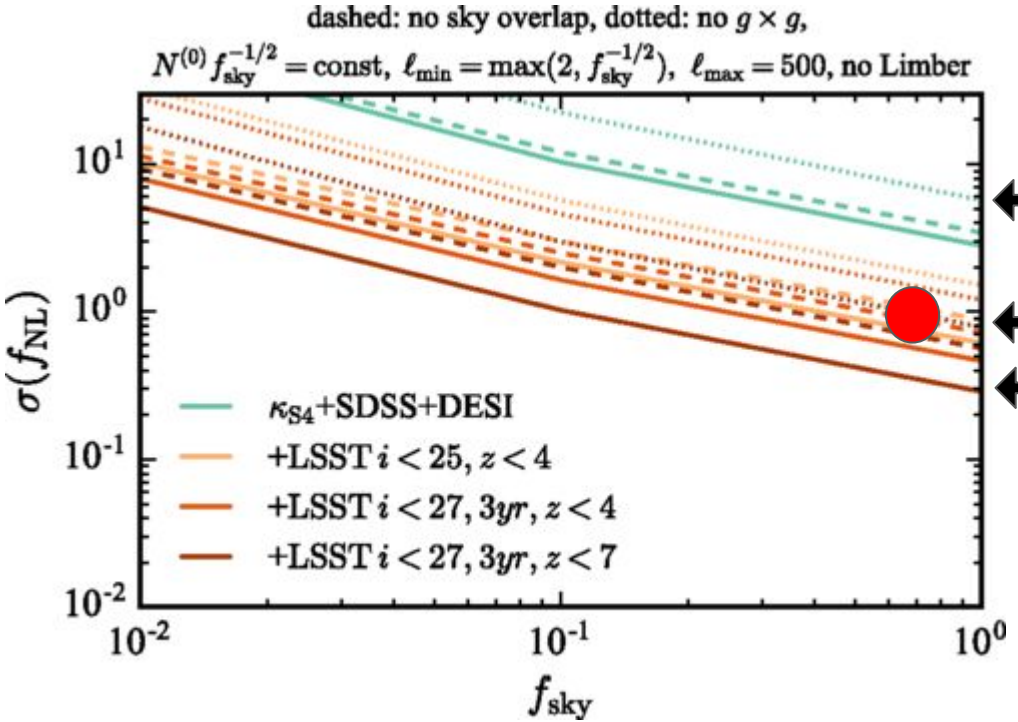


FIG. 1. Simulated maps of the same patch of the Universe, as measured with several different cosmological probes (from left to right): dark matter halos (detectable via the galaxies they host), galaxy clusters (with the size of the circles indicating the cluster mass), gravitational lensing of the CMB ($\kappa_{\rm CMB}$), the thermal Sunyaev

Recommendations: Complementarity

CF science goals – like non-gaussianity signature of inflation – require joint analysis



CMB-S4 + DESI, no sky overlap

Target measurement

CMB-S4 + DESI + LSST

Schmittfull & Seljak 2018

Recommendations: Complementarity

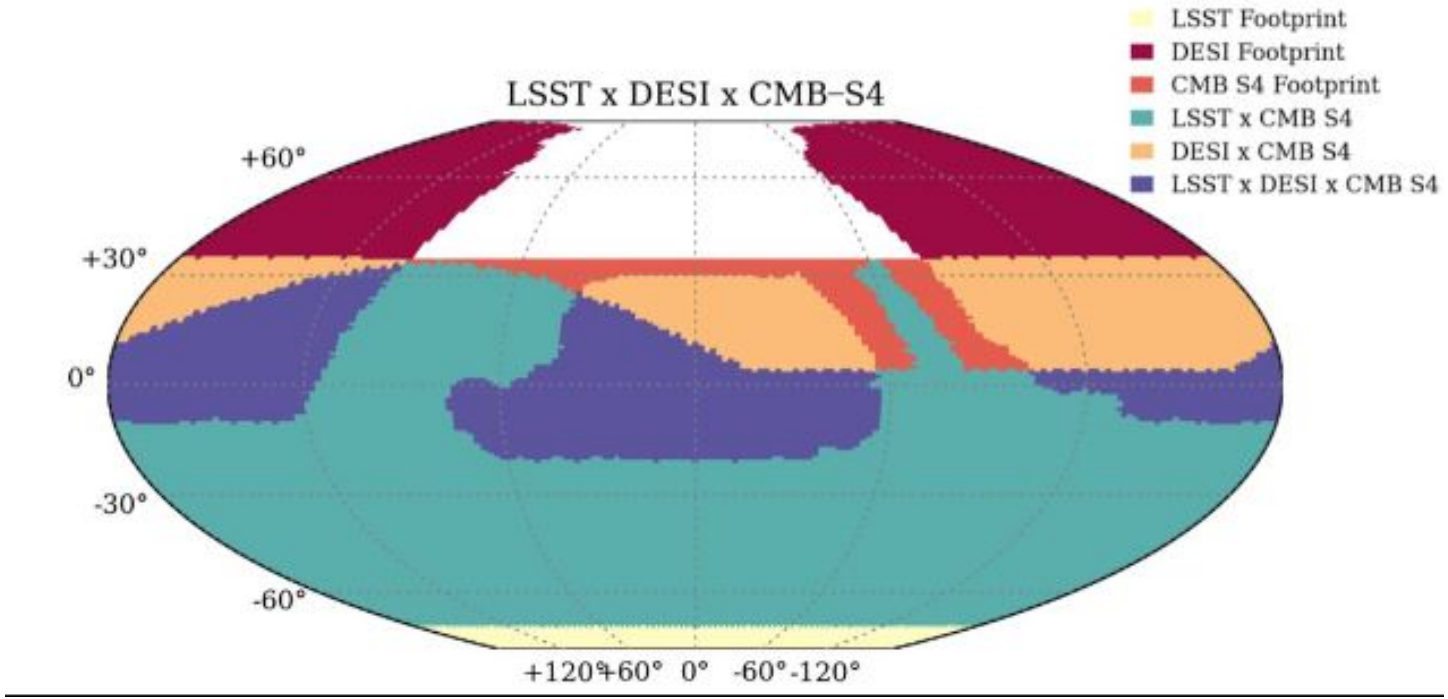
- No single experiment can reveal the nature of dark energy. Such a breakthrough will require data from a network of experiments, small and large, working in tandem to probe the early- and late-time Universe. At present, cross-survey analyses are challenging to initiate, organize, and fund. **We advocate for the creation of clear pathways to support cross-survey analyses as part of the core mission of the HEP Cosmic Frontier.**

  … including joint analysis tools and shared simulations

- Multi-messenger measurements of gravitational wave events are an emerging complementary technique for probing cosmology through standard sirens. **Support for coordination with future large (GW) facilities will enable maturation of this novel technique for measuring dark energy.**

Recommendations: Complementarity

Some measurements require maximum overlap between surveys (static sky or transient), others require only partial overlap



Complementarity – cross-survey of static probes

Necessary for full reach of Inflation, Dark Energy, indirect DM from wide-area surveys

- Coordinate overlap of survey footprints, i.e. extending LSST footprint to overlap existing and future redshift surveys
- Need to move from independent isolated surveys that only combine at the end (cosmological parameters) to **coordinated analysis**
- Joint Modeling and analysis: **coordination of survey strategies**, choices in modeling systematics, agreements for data sharing
- **Joint Simulations: necessary for joint analyses!**
- Archival storage of large unique data sets for future analysis
- Compute resources and access to supercomputers
- New initiatives (funding) needed to encourage cooperation between collaborations on combined probes: Cosmic Analysis Centers

”Opportunities from Cross-survey Analyses of Static Probes”, Eric J. Baxter, Chihway Chang, Andrew Hearin, Jonathan Blazek, Lindsey E. Bleem, et al. arXiv:2203.06795.

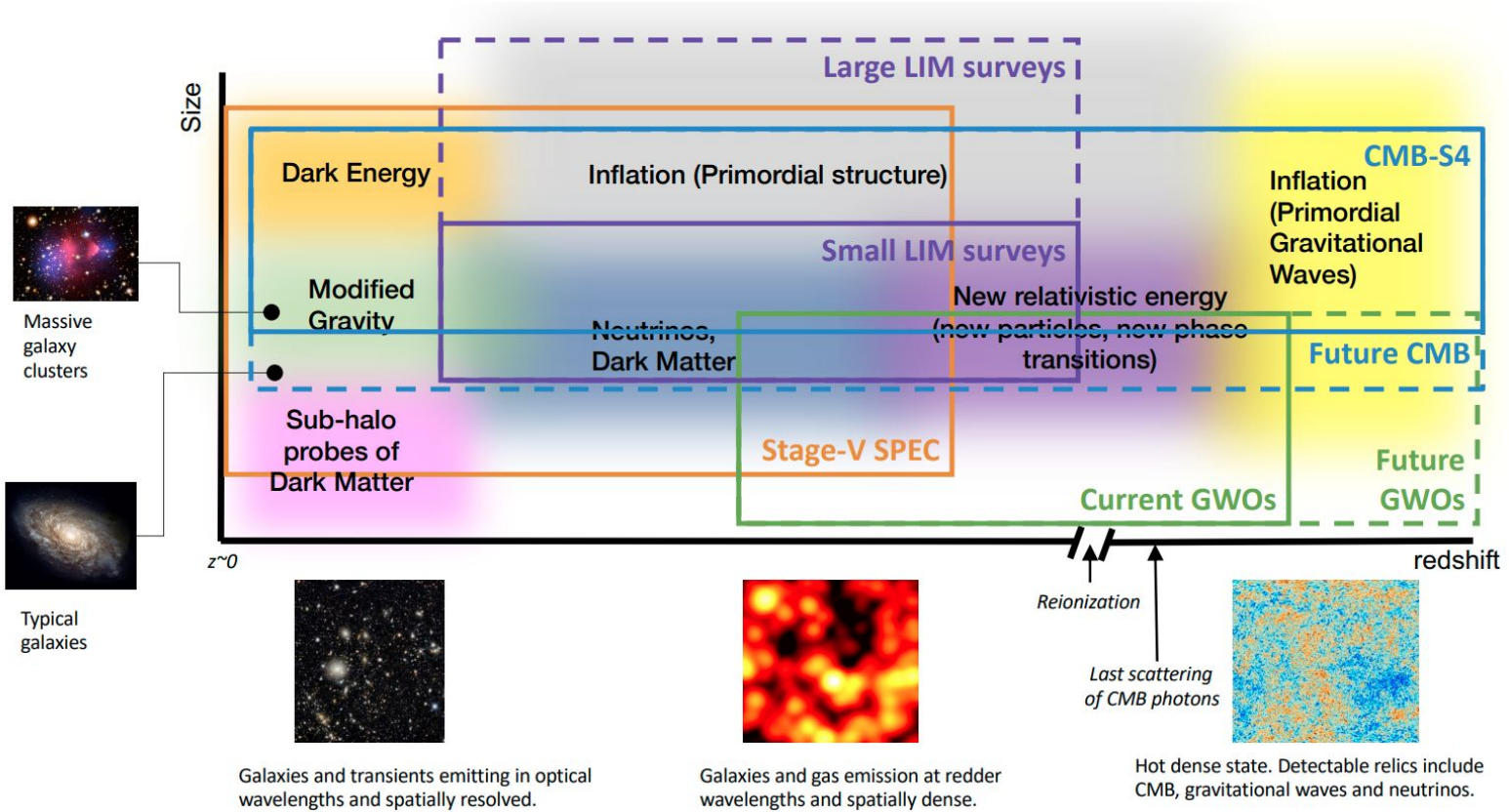
Complementarity – cross-survey of transient probes

Necessary for full reach of late-universe Dark Energy and BSM from transient probes

- Examples: new constraints on Hubble constant from detection of optical counterparts to GW detections and to strongly-lensed supernovae; follow-up Rubin SN detections; follow-up IceCube Neutrino Events
- **Advocate for development of a US-HEP multi-messenger program:**
  - Infrastructure to coordinate multiple facilities and data transfer
  - Repurposing (and support) of smaller (3-4m) telescopes for high-efficiency follow-up, search and discovery of GW and other transients
  - Theory and modeling to improve cosmological constraints
  - Develop agreements for dedicated target of opportunity observing across multiple facilities, negotiate schedules, develop decision process for target follow-up
  - Computing resources, access to High Performance Computing

”Multi-Experiment Probes for Dark Energy – Transients“, Alex G. Kim, Antonella Palmese, Maria E. S. Pereira, Greg Aldering, Felipe Andrade-Oliveira, et al. arXiv:2203.11226.

Cosmic Frontier New Facilities



Recommendations: Near-term facilities

- Given the pivotal role of CMB experiments in the landscape of particle physics and cosmology, and their phenomenal successes thus far, **we advocate for continuing the CMB program through strong support of the near-term construction and operation of CMB-S4**, crossing critical, motivated thresholds in the searches for inflationary gravitational waves and new particle species.
- **We advocate for the continued operations of DESI (DESI-II)** as an important part of the spectroscopic roadmap while a Stage V spectroscopic facility is designed and built.
- **We advocate for support of small- and medium-scale projects that enhance the science reach of studies of transients discovered by Rubin LSST and "standard sirens" detected by gravitational wave facilities.** Data from these projects will be combined with infrastructure that enables cross-experiment coordination and data transfer for time-domain astronomical sources and a US-HEP multi-messenger program with dedicated target-of-opportunity allocations on US-HEP and partner facilities.

Recommendations: Longer-term facilities

- Through the Snowmass2021 process, the HEP community has identified the pressing need for next- generation wide-field, massively multiplexed spectroscopic capabilities to complement LSST imaging. **We strongly advocate for the establishment, support and start of construction of a Stage V spectroscopic facility** in the coming decade.
- Recognizing the wealth of fundamental physics that can be probed by a much higher resolution and lower noise wide-area CMB survey, **we strongly advocate for support of design studies for Stage V CMB** to bring it to conceptual readiness for the next decade.
- New approaches such as millimeter and 21-cm line-intensity mapping (LIM) hold the promise of exceptional cosmological constraining power. However, the technological readiness of these programs must be further demonstrated before the community is prepared to invest fully in a large-scale project using these technologies. Thus, **we recommend a coordinated program of R&D to advance the technical readiness of these projects**.

Recommendations: Longer-term facilities

Cosmic Frontier has benefited from new technologies on survey telescopes

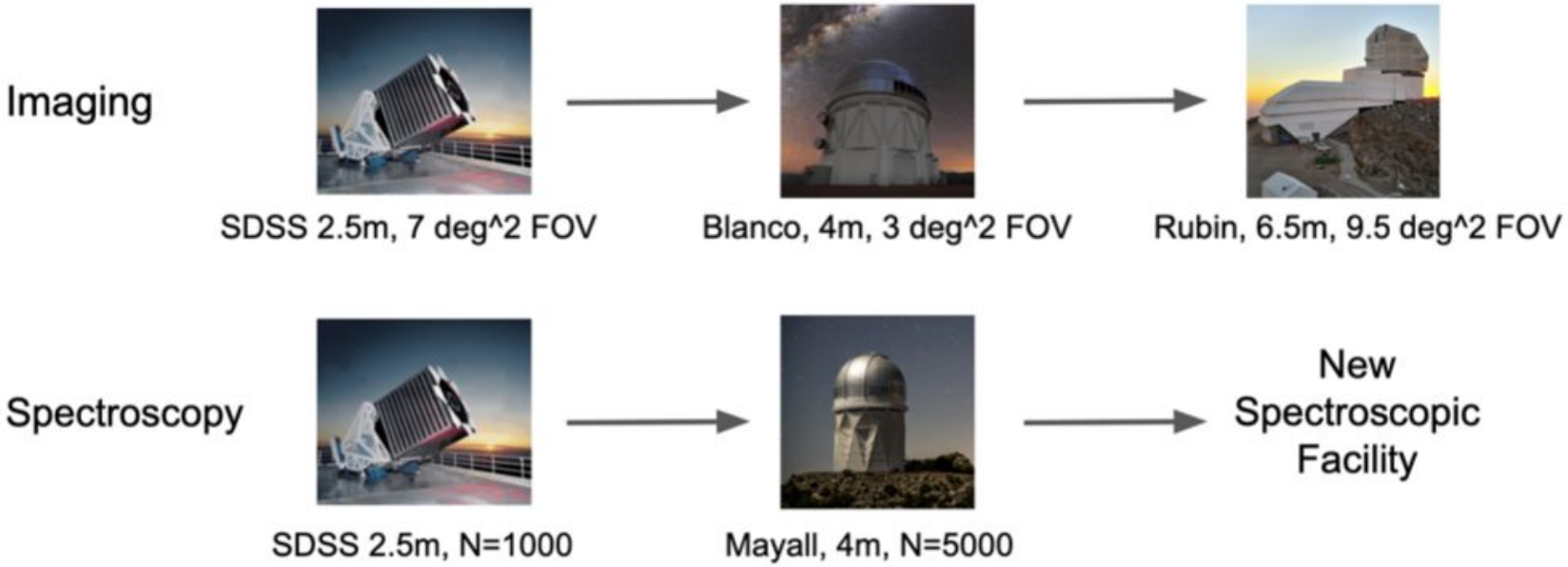
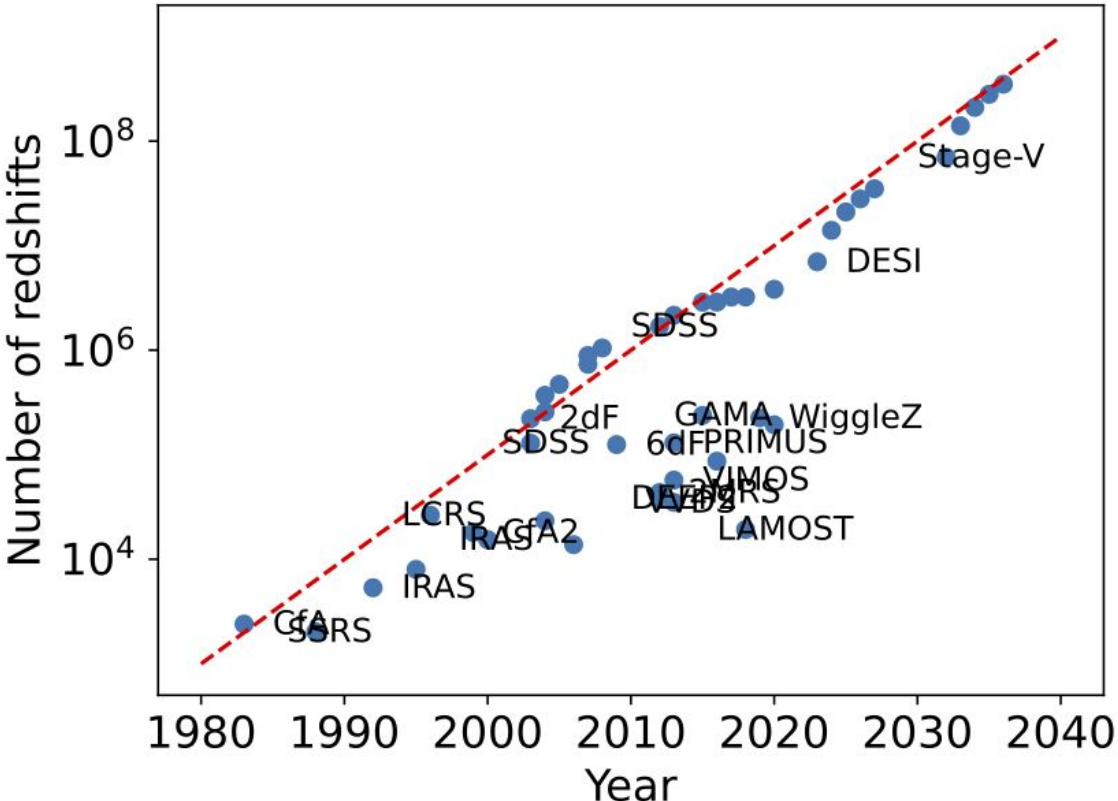


Figure 6-4. *Summary of imaging and spectroscopic surveys and facilities, ongoing and planned, that are supported by DOE/NSF partnerships. The international ground and space-based landscape of optical wide-field surveys, ongoing and planned, is very rich but for clarity is not represented here. SDSS had both imaging and spectroscopic capabilities, the Blanco telescope was used to carry out the DES, and the Mayall is currently used for DESI. In the near future, the Rubin Observatory will begin LSST. A new spectroscopic facility would open up new scientific opportunities.*

Recommendations: Longer-term facilities

Stage V spectroscopic recommended for Indirect DM, Dark Energy, Inflation, directly builds upon 25 years of DOE HEP investment



Extra slides

CF6: White Papers on Combined Probes, and Summary of New Facilities for Dark Energy (science motivation and description in subgroups)

White papers submitted to CF6 on combined probes:

- ”Opportunities from Cross-survey Analyses of Static Probes”, Eric J. Baxter, Chihway Chang, Andrew Hearin, Jonathan Blazek, Lindsey E. Bleem, et al. arXiv:2203.06795.
- ”Multi-Experiment Probes for Dark Energy – Transients“, Alex G. Kim, Antonella Palmese, Maria E. S. Pereira, Greg Aldering, Felipe Andrade-Oliveira, et al. arXiv:2203.11226.

Many facilities motivated and discussed in CF3,4,5 white papers (https://snowmass21.org/submissions/cf) for example:

- “Observational Facilities to Study Dark Matter” arXiv:2203.06200 (not just DM)
- ”CMB-S4 White Paper” arXiv:2203.08024
- ”Rubin Observatory after LSST”, arXiv:2203.07220
- Optical redshift surveys: DESI-II, FOBOS, MSE, MegaMapper, SpecTel arXiv:1907.11171
- ”21cm Radiation as a Probe of Physics Across Cosmic Ages ”, arXiv:2203.07864
- ”Future Gravitational-Wave Detector Facilities”, arXiv:2203.08228
- “Data Preservation for Cosmology “ arXiv: 2203.08113

Outline of CF6 report

1) Executive summary
2) Introduction
3) Optical Near IR Surveys and Facilities
    a) Rubin - operations will begin soon
    b) DESI - operations in progress - proposal to extend to DESI - II
    c) Future Widefield Multi-object spectroscopy - many options
    d) Complementarity - critical to maximize scientific reach
4) CMB
    a) CMB-S4 (from previous P5, joint NSF-DOE, has DOE CD-0 approval, funding limiting CD-1)
    b) Next generation CMB exp. : e.g. CMB-HD ~ 3x detectors, 6x resolution CMB-S4
5) Opportunities for Cross Survey Analysis - maximize scientific reach
    a) Static Probes
    b) Transient probes
6) Small Projects and Pathfinders: Spectroscopy, LIM, 21-cm
7) Multi-Messenger Probes: GW provide new powerful constraints on cosmology

Status of CF6 report

Writing was open to all CF6 contributors, draft submitted June 28

Google doc collecting comments:
https://docs.google.com/document/d/1f2m7oOfqjL4EgT-eQheGDHtT-H47AMlGX9QxVz6bE9I/edit?usp=sharing